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Title: Nuclear Material Measurement Contribution to the Material Balance Evaluation


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**NONPROLIFERATION AND
ARMS CONTROL (NPAC)**

Nuclear Material Measurement Contribution to the Material Balance Evaluation

**Fundamentals of Non-Destructive Assay for
International Safeguards**

Los Alamos National Laboratory
September 29, 2017

Bill Geist
Los Alamos National Laboratory

- SAFEGUARD** NUCLEAR MATERIALS TO
PREVENT THEIR DIVERSION OR THEFT
- CONTROL** THE SPREAD OF WMD-RELATED
MATERIAL, EQUIPMENT AND TECHNOLOGY
- NEGOTIATE, MONITOR AND VERIFY**
COMPLIANCE WITH INTERNATIONAL
NONPROLIFERATION AND ARMS CONTROL
TREATIES AND AGREEMENTS
- DEVELOP** PROGRAMS AND STRATEGIES TO
ADDRESS EMERGING NONPROLIFERATION
AND ARMS CONTROL THREATS AND
CHALLENGES

1

Estimated Module Duration: 30 minutes

Required Tools and Materials:

1. Projector, screen, laptop with Word and PowerPoint programs
2. Participant guides, with slides and supplemental material

References:

1. INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safeguards Glossary, International Nuclear Verification Series No. 3, IAEA, Vienna (2003). <http://www-pub.iaea.org/books/IAEABooks/6570/IAEA-Safeguards-Glossary>
2. INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safeguards Technical Manual, Part F Statistical Concepts and Techniques, Volume 3, IAEA-TECDOC-261, IAEA Vienna (1982). http://www-pub.iaea.org/MTCD/publications/PDF/te_261_web.pdf

Supporting Documents:

1. None

Job Aids:

1. None

Terminal Learning Objectives (TLOs):

- TLO-1: Describe the impact that NDA measurements have on the material balance evaluation and the determination of MUF

Enabling Learning Objectives (ELOs):

- ELO-1: Discuss the role of measurements in the evaluation of a material balance
- ELO-2: State the material balance equation
- ELO-3: List the objectives in performing a material balance evaluation
- ELO-4: Describe the similarities and differences in performing a material balance evaluation between an item and bulk facility type
- ELO-5: Explain how sigma MUF is calculated and used in a material balance evaluation
- ELO-6: Discuss the role of operator's measurements and inspector's measurements in a material balance evaluation

Additional Information for Students:

Terminal Learning Objective


Describe the impact that NDA measurements have on the material balance evaluation and the determination of MUF.


Instructor Notes:

Review learning objectives with the participants.


Encourage participants to ask questions during the lecture.

Additional Information for Students:





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Enabling Learning Objective


- Discuss the role of measurements in the evaluation of a material balance.
- State the material balance equation
- List the objectives in performing a material balance evaluation
- Describe the similarities and differences in performing a material balance evaluation between an item and bulk facility type.
- Explain how sigma MUF is calculated and used in a material balance evaluation.
- Discuss the role of operator's measurements and inspector's measurements in a material balance evaluation.


Instructor Notes:

Review learning objectives with the participants.

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Additional Information for Students:





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Function of measurements in the MBE

Nuclear Material Measurements are used in the material balance evaluation (MBE) in several ways:


- The Operator's accountancy measurements and associated uncertainties are used to calculate the material unaccounted for (MUF) and uncertainty on the MUF.
- The Inspector's verification measurements are used to ensure
 - that the operator's measurement systems are functioning correctly to give confidence in the MUF evaluation.
 - that the operator's declarations are correct.

Measurements of nuclear material are a very important aspect in the material balance evaluation process. The measurements are used to ensure that the operator's measurements systems are in control. This will give greater confidence in the MUF and sigma MUF values generated during a material balance evaluation. Measurements are also used to ensure that the operator's

declaration is correct.

Instructor Notes:

Additional Information for Students:



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Material Balance Evaluation

A material balance evaluation is performed whenever the material balance is closed to determine if any non-zero MUF (material unaccounted for) can be explained by measurement uncertainty.

$$MUF = PB + I - D - PE$$

where


- PB is the beginning physical inventory (same from PE from prior MBP)
- I is the sum of increases to the inventory
- D is the sum of decreases from the inventory
- PE is the ending physical inventory

Instructor Notes:


In the material balance evaluation performed by the operator, the uncertainties associated with the measurement system used to determine the declared amounts of material, for each of the for components of the material balance equation, are applied to the item or stratum amounts to determine the uncertainty of the material balance. The operator uses the MUF and associated uncertainty for both safeguards, safety, and security goals. A zero MUF indicates that no material has gone missing or that there is no excessive holdup in the facility. The uncertainty on the MUF is also an indication that the measurement systems are performing within acceptable parameters.

The IAEA material balance evaluation includes: a) evaluation of the operator's declared MUF and the cumulative MUF, b) evaluation of the operator-inspector difference, c) evaluation of the inspector's estimate of MUF, d) comparison of sigma MUF with the international standards of accountancy to determine if the operator's measurement system is adequate for safeguards purposes.

Additional Information for Students:



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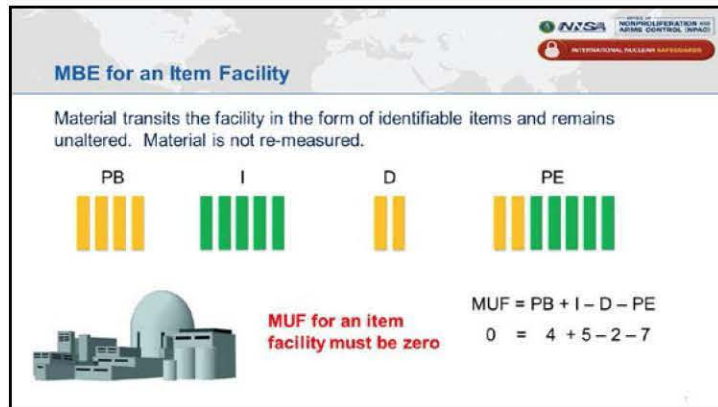
Objectives of a Material Balance Evaluation

- Detect diversion of declared nuclear material and any undeclared production
- Check consistency of the operator's declarations
 - Acceptability of operator's declarations
 - Compliance of the operator's measurement systems with international standards
 - Review patterns and trends in the measurement data
- Check agreement between the operator's declarations and reality (is the operator's declaration correct)
 - Verify presence of items and material (gross defect measurements)
 - Perform quantitative measurements (partial and bias measurements)

Instructor Notes:

To check the consistency of the operator's declarations, the IAEA will do a thorough review of the operator's books. This will ensure that the accounting records are reasonable to comparing record keeping documents and also ensure that the amount of material flow is in agreement with the design information of the facility. They will check to ensure that the operator's measurement systems are in control and yielding results that are acceptable when compared to international norms. The IAEA will review the patterns in the MUF, CMUF, and sigma MUF values over many material balances to ensure agreement with normal statistical fluctuations. The IAEA will also perform measurements to ensure the correctness on the operator's declaration. The type and number of measurements is based on a sampling plan.

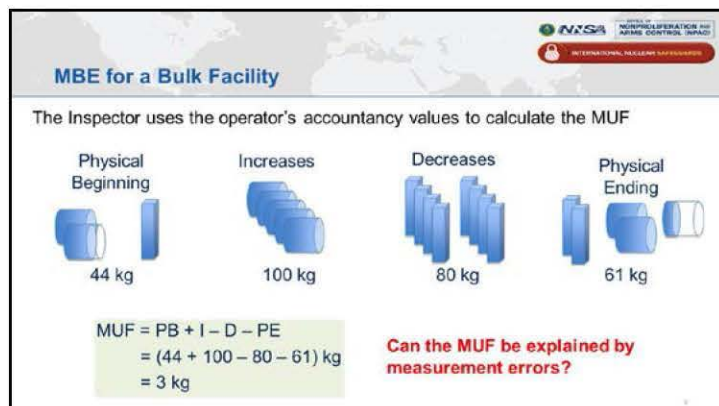
Additional Information for Students:



Instructor Notes:

This is a simple example of a material balance evaluation of a power reactor. The yellow items could be fuel assemblies already located at the facility at the beginning of the material balance period (MPB) and the green items are new assemblies delivered to the facility during the MBP. In this example, 4 items were at the facility at the start of the MBP, 5 new assemblies were delivered, and 2 assemblies were shipped off site during the MBP. At the end of the MBP, there were 7 assemblies remaining (2 yellow and 5 green). Putting these number into the MBE equation results in a zero MUF. Since in an item facility there is no processing of material the MUF is expected to always be zero.


Additional Information for Students:




Instructor Notes:

The accountancy mass values are obtained from the operators accountancy measurements. Most of the accountancy measurements are based on both nondestructive and destructive assay techniques. Since all measurements have uncertainties, a non zero MUF is expected. In this example, 3 kg of material is missing. Is this material really missing or can it be justified as an uncertainty.

Additional Information for Students:





Calculation of the σ MUF

$$\sigma \text{MUF}^2 = \sigma \text{PB}^2 + \sigma \text{I}^2 + \sigma \text{D}^2 + \sigma \text{PE}^2$$

- The **operator's measurement uncertainty** associated with each of the four material balance components are combined with the material quantities to determine the total uncertainty on the MUF.
- Ideally σ MUF should be as small as reasonably possible and must be less than a significant quantity.
- Target values for routinely achievable random and systematic measurement uncertainties are published as International Target Values (ITV)
- The inspector checks to ensure that σ MUF is reasonable to prevent the operator from hiding a diversion of material in σ MUF.
- The long term cumulative trend of MUF and σ MUF is also checked.

In the material balance evaluation, the uncertainties associated with the measurement system used to determine the declared amounts of material, for each of the four components of the material balance equation, are applied to the item or stratum amounts to determine the uncertainty of the material balance.

Diversion into MUF is a concealment method in which an amount of declared material M is removed from a material balance area and the accounting records are adjusted to account for the amount M removed. Because the operator's accounting records reflect the removal of M, there is no falsification of these records. This diversion strategy causes an imbalance in the MUF equation and the diversion amount M shows up as part of a non-zero MUF. The diverter assumes that the uncertainty of MUF would be large enough to hide the removal. This type of diversion would be detected through observation of an unusually large value of MUF. However, if sigma MUF is large because of poor measurement quality, then the diversion can be concealed.

Instructor Notes:


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Inspector Verification Measurements

- Verification measurements are performed to ensure that there are no falsifications in the operator's mass accountancy declarations.
- A subset of the total items in the inventory is measured as determined by the sample plan.
 - The measurement uncertainty of a chosen technique will impact the sample size needed to ensure no diversion of material.
- The measurements performed on the subset is extrapolated to the entire inventory to ensure that there is no diversion of nuclear material.

Instructor Notes:

Diversion into D (operator inspector difference) is a concealment method in which the diverter removes an amount of declared material but does nothing to the operator's accounting records to hide the diversion. The accounting records are therefore now false (and have thus been falsified). In this case, the MUF will be statistically consistent with zero.

This type of diversion causes a discrepancy (i.e. defect) between the material declared to be present and the material actually present. The only way to detect the diversion is for the inspector to measure the container(s) from which material was removed and to compare the measured value with the operator's declared value. This scheme is referred to as diversion into D because it can be detected through observation of an unexpectedly large value of the operator – inspector difference. Diversion into D can be concealed if the inspector measurement quality is poor and the uncertainty of D is large.

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Summary

- A material balance evaluation is performed by an inspector to ensure that no nuclear material has been diverted within the MBP.
- The operator's measurements and associated uncertainties are used to determine the MUF and sigma MUF.
- The inspector's measurements are used to check the operator's declarations and are extrapolated to ensure consistency with the MUF value.

Instructor Notes: